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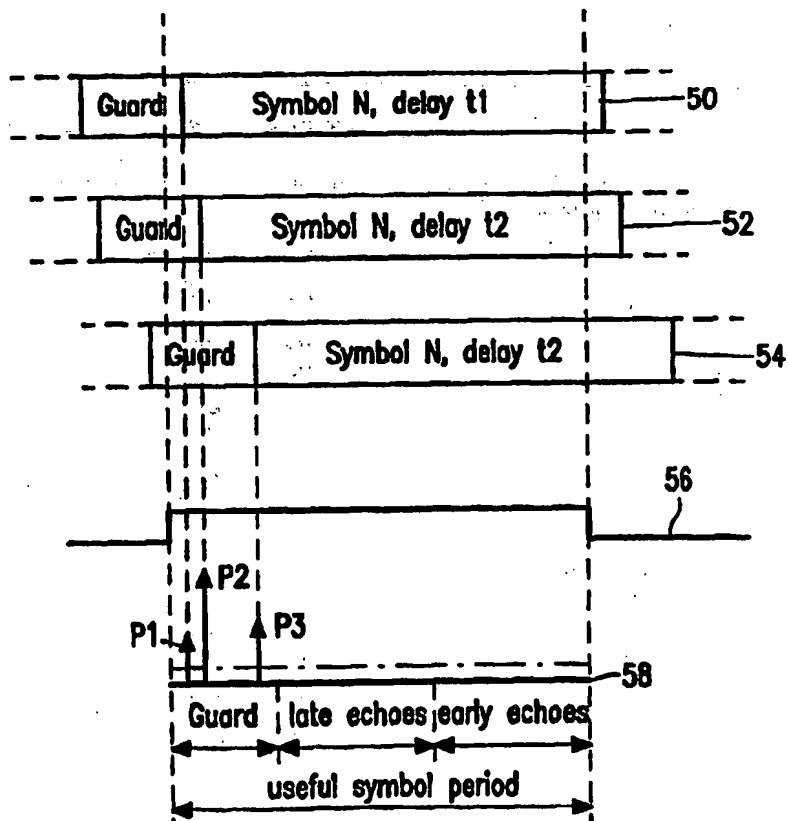
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(54) Title: TRANSMISSION SYSTEM WITH IMPROVED SYMBOL PROCESSING

(57) Abstract

In OFDM transmission use of an FFT is made for demodulating all carriers simultaneously. In order to prevent adverse influence of intersymbol interference due to multi path propagation, it is known to determine the impulse response of the transmission medium and to adapt the FFT window accordingly. According to the invention the centre of gravity of the impulse response is used rather than the first significant value of the impulse response. This has the advantage that the influence of deep fading has less influence on the selection of the FFT window, resulting in an improved performance.



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Transmission system with improved symbol processing

The present invention is related to a transmission system comprising a transmitter for transmitting digital symbols via a transmission medium to a receiver, the receiver comprises means for estimating the impulse response of the transmission medium, the receiver further comprises processing means for processing in dependence of the impulse response of the transmission medium the received signal during a predetermined processing period.

The invention is further related to a receiver for use in such a transmission system.

A transmission system according to the preamble is known from the paper "General-purpose and application-specific design of a DAB channel decoder" by F. van de Laar, N. Philips and R. Olde Dubbelink in EBU Technical Review, Winter 1993, pp. 25-35.

In transmission of digital symbols over radio channels several transmission impairments have to be dealt with. A first impairment is so called multi-path transmission, which is caused by transmission of a signal from a transmitter to a receiver via one direct path and/or via one or more indirect paths due to reflection by buildings and other structures. In digital transmission systems multi-path transmission results into intersymbol interference, leading to an increased error probability of the received digital symbols. A further impairment which is consequence of multi-path transmission is frequency selective fading. This means that fading can occur which heavily depends on the signal to be transmitted. With increasing symbol rate the adverse effect of the previously mentioned impairments becomes more manifest.

Important improvements with respect to the vulnerability to the above mentioned impairments can be obtained by using a multiple carrier signal comprising a multiple of carriers, at least a part of them being modulated with the digital symbols to be transmitted. A sequence of symbols having a first symbol rate is subdivided into N parallel sequences of symbols having a second symbol rate being a factor N lower than the first symbol rate. Said N sequences of symbols are modulated on N carriers. In the receiver these

N carriers are demodulated, and decisions about the values of the received symbols are made. The N received sequences of symbols can be combined to one single sequence of output symbols. Due to the reduction of the transmission rate of each sequence of symbols the influence of intersymbol interference due to multipath propagation is decreased

5 accordingly.

Despite the fact that the present invention is presented in relation to multicarrier transmission, the scope of the present invention is not limited thereto. It is perfectly possible to apply the present invention to a single carrier transmission system.

To reduce the effects of multipath transmission even more the received
10 signal is processed during a predetermined processing period which can be shorter than said symbol period. The difference between the symbol period and the processing period is often called the guard band. The position of the processing period is chosen such that the received signal does not contain parts arising from subsequently transmitted symbols due to multipath propagation. If the so called delay spread is smaller than the guard interval it is always
15 possible to find a position of the processing period in which no intersymbol interference is present. In order to be able to position the processing period correctly, the impulse response of the transmission medium is determined. It is observed that it is possible that the processing period is not shorter than the symbol period. This can result in some intersymbol interference. By selecting the position of the processing period with respect to the symbol
20 period in a proper way, it is possible to minimise said intersymbol interference.

An object of the present invention is to provide a transmission system according to the preamble in which the correct position of the processing period with respect
25 to the symbol period is determined in a reliable way.

Therefor the transmission system according to the invention is characterised in the receiver comprises means for positioning the processing period with respect to the symbol duration in dependence on the central position of an auxiliary signal representative of the impulse response of the transmission medium.

30 By deriving the position of the processing period from the central position of an auxiliary signal representative of the impulse response, a correct position is obtained. If the impulse response is symmetrical around a reference instant, the processing period can be positioned centrally within a symbol period. The symbol period then overlaps the processing period with an amount equal to half the guard space G. The center position of the impulse

response is than equal to said reference instant. If the impulse response has a post cursor larger than the precursor, the center position will shift to a later instant. The larger post cursor leads to increased intersymbol interference in the beginning of the symbol interval. By shifting the processing interval to a later instant it is obtained that the intersymbol
5 interference at the beginning of the symbol interval has no adverse effect on the transmission quality any more.

If the impulse response has a pre cursor larger than the post cursor, the center position will shift to a earlier instant. The larger pre cursor leads to increased intersymbol interference in the end of the symbol interval. By shifting the processing interval
10 to a earlier instant it is obtained that the intersymbol interference at the beginning of the symbol interval has no adverse effect on the transmission quality any more. An additional advantage is the substantial reduction of the influence of deep fades on the synchronisation behaviour. The centre position of the impulse response can e.g. be the "centre of gravity" of the impulse response, or the average position of the most significant samples of the impulse
15 response.

An embodiment of the invention is characterised in that the means for positioning the processing period are arranged for weighting parts of the auxiliary signal in dependence of their position with respect to the centre position of the auxiliary signal.

By emphasizing parts of the auxiliary signal remote from the centre
20 position it is obtained that parts remote from the centre position of the auxiliary signal lead to an firm correction of the position of the processing period. This firm correction is required because these remote parts introduce substantial intersymbol interference, especially is they are positioned more than $G/2$ away from the centre position of the auxiliary signal.

A further embodiment of the invention is characterised in that the means
25 for positioning the processing period comprise compression means for obtaining an auxiliary signal having a smaller duration than the impulse response of the transmission medium.

In case of a Raleigh fading channel with a large delay spread it can occur that the centre position of the auxiliary signal changes rapidly over a large range. By compressing the auxiliary signal the range over which the centre position varies is reduced.
30 This leads to a more smooth control of the position of the processing window.

The invention will now be explained in more detail with reference to the drawing. Herein shows

Fig. 1, a transmission system in which the present invention can be applied;

Fig. 2, processing period positioning means according to the invention;

Fig. 3, a graphical representation of the selection of the processing
5 window according to the invention;

Fig. 4, a graphical representation of a way to emphasize the remote parts of the auxiliary function;

Fig. 5, a graphical representation of a way to reduce the duration of the auxiliary function;

Fig. 6, several functions $F(k)$ to be used in the calculation of a modified
10 centre of gravity.

In the transmission system according to Fig. 1 the digital symbols to be
15 transmitted is applied to a transmitter 4. The output of the transmitter 4 is connected to a transmitting antenna 6.

A receiving antenna 10 is connected to a first input of a receiver 8. In the receiver 8 the input is connected to an RF unit 12. An output of a local oscillator 28 is connected to a second input of the RF unit 12. The output of the RF unit 10 is connected to
20 an input of a demodulator 14. The output of the demodulator 14 is connected to an input of the processing means being here an FFT processor 16. The output of the FFT processor is connected to a decoder 18, a first input of a synchronisation processor 22 and to the means for estimating the impulse response of the transmission medium 30. An output of the means 30 is connected to a second input of the synchronisation processor 22. A first output of the
25 synchronisation processor 22 is connected to an input of the positioning means 24 for the FFT processor 16. A second output of the synchronisation processor 22 is connected to a control input of a time base unit 26, and a third output of the synchronisation processor 22 is connected to a control input of the local oscillator 28. The combination of the
synchronisation processor 22, the positioning means 24 and the time base 24 constitute the
30 means for positioning the processing period with respect to the symbol period. At the output of the decoder 18 the signal to be transmitted is available.

A typical transmission system where the present invention can be applied is the Digital Audio broadcast System (DAB) as disclosed in the previously mentioned paper. The transmitter 2 in Fig. 1 is assumed to generate a signal comprising a multiple of carriers.

Such a signal is often called an OFDM signal (Orthogonal Frequency Division Multiplex). The digital symbols presented at the input of the transmitter are converted in blocks of N parallel symbols. Said blocks of N parallel symbols are encoded, time and frequency interleaved to obtain blocks of N coded and interleaved symbols. Each of such symbols are modulated on one of the plurality of carriers. This modulation is performed by an inverse Fourier transformer. The output of said inverse Fourier transformer is upconverted to the desired carrier frequency and subsequently amplified.

An OFDM signal received by the receiver 6 is amplified and converted to an IF signal by the RF unit 10. For said conversion the RF unit 10 is supplied with a local oscillator signal generated by the local oscillator 12. The output signal of the RF unit 10 is demodulated by the demodulator 14. The demodulator 14 presents its output signal in in-phase and quadrature components. To obtain the digital symbols modulated on the plurality of carriers, the output of the demodulator 14 is applied block wise to the FFT processor 16. In order to minimise the effect of intersymbol interference, the FFT processor 16 receives a signal from the positioning means 24 defining the position of the processing period with respect to the symbol period. This signal is derived by the synchronisation processor 22 from the impulse response determined by the estimation means 30 for estimating the impulse response of the transmission medium. The estimation means 30 are arranged to derive the impulse response of the transmission medium from the output signal of the FFT processor 16. For determination of the impulse response of the transmission medium use is made of a reference symbol's transmitted at the beginning of an OFDM frame. The symbol's can be regarded as a vector comprising of N complex elements. The output signal r of the FFT processor 16 can be regarded as a sequence of vectors each comprising N complex elements. The beginning of an OFDM frame is indicated by a so-called null symbol which consists of a period in which the amplitude of the transmitted signal is almost zero. Using this null symbol a first estimate for the position of the reference symbol in the received signal can be made. The impulse response can now be found by calculating:

$$h(k) = FFT^{-1}\{r \cdot s^*\} \quad (1)$$

In (1) $r \cdot s^*$ means the element wise product of the vector r and the complex conjugate of the vector s.

The synchronisation processor 22 also provides a frequency correction signal for controlling the local oscillator 28 in order to reduce the frequency offset of the receiver. It is observed that the frequency correction can also be obtained by a phase rotator

such as a CORDIC processor in the signal path between RF unit 12 and decoder 18. The synchronisation processor also provides a control signal for adjusting the time base 26 in order to synchronise it to the time base of the transmitter.

At the output of the FFT processor 16 the coded and interleaved symbols
5 are available. These symbols are de-interleaved and decoded by the decoder 18 to obtain the reconstructed digital symbols.

In the synchronisation processor 22 the second input is connected to an input of first means 32 for determining a central position of the auxiliary signal, in order to derive a first auxiliary signal from the channel impulse response and to determine a first
10 central position of this auxiliary signal. An output of the means 32 is connected to an input of a comparator 34. An output of the comparator 34 is connected to an input of a filter 36. An output of the filter 36 is the first output of the synchronisation processor 22 and is used for positioning the processing period of the FFT processor 16.

The second input of the synchronisation processor 22 is also connected to
15 an input of second means 38 for determining a central position of the auxiliary signal, in order to derive a second auxiliary signal from the channel impulse response and to determine a second central position of this auxiliary signal. An output of the means 38 is connected to an input of a comparator 40. An output of the comparator 40 is connected to an input of a filter 42. An output of the filter 42 is the second output of the synchronisation processor 22
20 and is used to control the digital time base of the receiver.

The output of a frequency error detector 44 is connected to an input of a filter 46. The output of the filter 46 is the third output of the synchronisation processor 22 and is used to control the local oscillator 28.

The means 32 and 38 derive a first and a second auxiliary signal from the
25 impulse response, and calculate a central position of said auxiliary signals.

The auxiliary signal can e.g. be derived from the impulse response by calculating its absolute value or its squared value. A suitable measure of said central position is the centre of gravity of the auxiliary signal. If the auxiliary signal can be written as a time discrete signal $P(k)$ for

the centre of gravity one finds:

$$G = \frac{\sum_{k=1}^N k \cdot P(k)}{\sum_{k=1}^N P(k)} \quad (2)$$

In the comparators 34 and 40 the actual position of the centre positions of the auxiliary signals as calculated by the means 32 and 38 are compared with a desired values of said central positions.

5 By comparing said first central position with a first desired reference position in comparator 34, a control value can be determined by filter 36. The output of filter 36 can be used to modify the position the position of the processing period of FFT processor 16 within the symbol period by means of the position control means 24 in such a way that said central position moves towards the reference position of comparator 34. In a
10 typical application, the position of the processing window is defined as an offset with respect to a reference signal generated by the time base 26. Generally, the range of the position control is limited to the symbol period or the guard period. It can be used to react on fast changes of the channel impulse response. A permanent large offset indicates a misalignment of the digital time base. The filter 36 will be a high pass filter in order to enable a fast
15 reaction on fast changes of the impulse response, and to suppress any action on a permanent offset which has to be dealt with by the time base 26.

By comparing said second central position with a second desired reference position in comparator 40, a control value can be calculated in filter 42. The control output of filter 40 can be used to adjust the digital time base 26 in such a way that said central
20 position moves towards the reference position of comparator 40. The time base can be adjusted by controlling the digital clock oscillator and/or the clock dividers in the time base. In a typical application the filter 46 will be a low pass filter and the control output will be used to compensate tolerances of the digital clock oscillator and to keep the time base locked to the received frames.

25 Modifying the position of the processing window with respect to the received symbols can also be done by adjustment of the time base only. In this case the offset of the positioning means 24 with respect to the time base reference should have a fixed value.

The frequency error detector 26 derives a measure for the frequency

offset of the receiver. This measure is used to correct the frequency of the local oscillator.

In Fig. 3 graphs 50, 52 and 54 show a OFDM symbol reaching the receiver via several paths after a delay t_1 , t_2 and t_3 respectively. The received OFDM signal is a combination of the signals according graphs 50, 52 and 54. Graph 56 shows a suitable
 5 processing period in which no contribution from OFDM symbols other than the present one is received. Graph 58 shows the auxiliary function derived from the impulse response calculated using (1) in the processing period as indicated in Fig. 3. A preferred position GP for the centre of gravity of the auxiliary function is located at $GL/2$ from the beginning of the processing period as is indicated in graph 58, where GL indicated the length of the
 10 guard. By calculating the centre of gravity using (2) and comparing it with the preferred value GP, a correction signal for adjusting the processing period and/or the digital time base can easily be derived.

Graph 60 in Fig. 4 shows an auxiliary signal having part remote from the centre position. The early echos have been drawn in the actual time order, in
 15 contradistinction to graph 58 in Fig. 3 where the auxiliary signal is drawn as it is stored in the output buffer of the FFT processor 16. In graph 62 an auxiliary signal comprising remote parts is drawn. From this signal a modified auxiliary signal having emphasised remote parts. This can be done by adding all values of the early echos to obtain a value P_{ee} , multiplying the value P_{ee} by a gain factor K_e and positioning the value so obtained at position $k=N/2-$
 20 $G/2$. For the late echos the same is done by adding all values of said late echos to obtain a value P_{le} , multiplying the value P_{le} by a gain factor K_l and positioning the value so obtained at position $k=N/2+G/2$. In graph 62 the modified auxiliary signal is drawn. It is observed that alternative ways exist for obtaining a modified auxiliary signal, such as multiplying the values of the auxiliary function with a factor that increases with increasing distance from the
 25 centre position.

In graph 64 of Fig. 5 the modified auxiliary signal according to graph 62 of Fig. 4 is redrawn, but the period G is subdivided in sections E_3 , E_2 , E_1 , M , L_1 , L_2 and L_3 . A further modified auxiliary signal with a reduced duration is obtained by combining the sections E_1 , E_2 and E_3 in a first section, and combining the sections L_1 , L_2 and L_3 in a
 30 second section. This way of combining is shown in graph 66 of Fig. 5. From said graph it is clear that the duration of the further auxiliary signal is reduced.

A modification of the auxiliary signal can be useful for emphasizing or de-emphasizing certain parts of the impulse response. It can also be used to reduce the jitter on the value of G in case of , for example , a large delay spread in the transmission medium. In

general, the modification of the auxiliary signal can be expressed as a function $F(k)$ which can be used to calculate a modified centre of gravity G_m as follows:

$$G_m = \frac{\sum_{k=-N/2}^{N/2} F(k) \cdot P(k)}{\sum_{k=-N/2}^{N/2} P(k)} \quad (3)$$

For convenience the range of k is made symmetrical around 0. In Fig. 6, some functions $F(k)$ are shown. Graph a in Fig. 6 shows $F(k)$ for the calculation of the centre of gravity without modification of the auxiliary function. This is equivalent to (2). Graph b shows $F(k)$ for the modifications represented by graph 66 in Fig. 5. It is clear that also other shapes for $F(k)$ can be defined. U

CLAIMS

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1. Transmission system comprising a transmitter for transmitting digital symbols via a transmission medium to a receiver, the receiver comprises means for estimating the impulse response of the transmission medium, the receiver further comprises processing means for processing in dependence of the impulse response of the transmission medium the received signal during a predetermined processing period, characterised in that the receiver comprises means for positioning the processing period with respect to the symbol duration in dependence on the central position of an auxiliary signal representative of the impulse response of the transmission medium.

2. Transmission system according to claim 1, characterised in that the means for positioning the processing period are arranged for weighting parts of the auxiliary signal in dependence of their position with respect to the centre position of the auxiliary signal.

3. Transmission system according to claim 2, characterised in that the means for positioning the processing period are arranged for emphasizing parts of the auxiliary signal lying outside an predetermined interval around the centre position.

20 4. Transmission system according to one of the claims 1 to 3, characterised in that the transmitter is arranged for transmitting the digital symbols according to a multicarrier modulation scheme.

5. Transmission system according to one of the claims 1 to 4, characterised in that the means for positioning the processing period comprise compression means for obtaining an auxiliary signal having a smaller duration than the impulse response of the transmission medium.

6. Receiver for receiving digital symbols transmitted via a transmission medium, the receiver comprises means for estimating the impulse response of the transmission medium, the receiver further comprises processing means for processing in dependence of the impulse response of the transmission medium the received signal during a predetermined processing period, characterised in that the receiver comprises means for positioning the processing period with respect to the symbol duration in dependence on the central position of an auxiliary signal representative of the impulse response of the transmission medium.

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7. Receiver according to claim 6, characterised in that the means for positioning the processing period are arranged for weighting parts of the auxiliary signal in dependence of their position with respect to the centre position of the auxiliary signal.
8. Receiver according to claim 7, characterised in that the means for positioning the processing period are arranged for emphasizing parts of the auxiliary signal lying outside an predetermined interval around the centre position.
9. Receiver according to claim 8, characterised in that said receiver is arranged for receiving a signal being modulated according to a multi carrier modulation scheme.
10. Receiver according to one of the claims 5 to 9, characterised in that the means for positioning the processing period comprise compression means for obtaining an auxiliary signal having a smaller duration than the impulse response of the transmission medium. U

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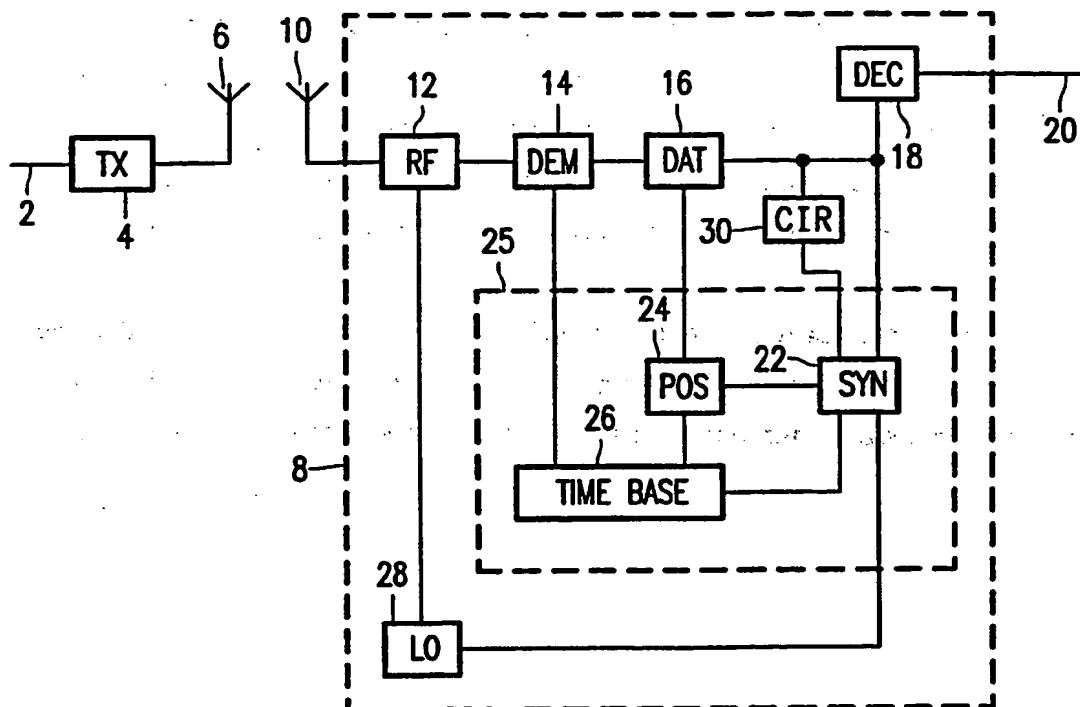


FIG. 1

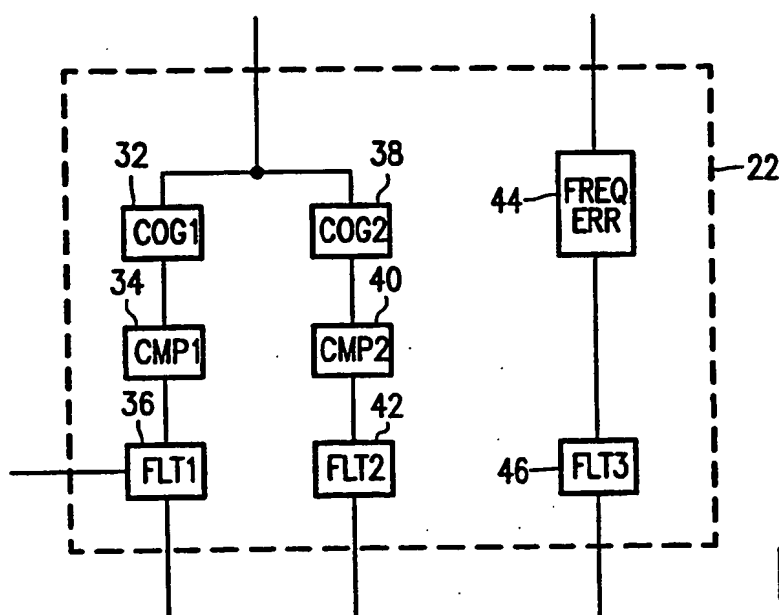


FIG. 2

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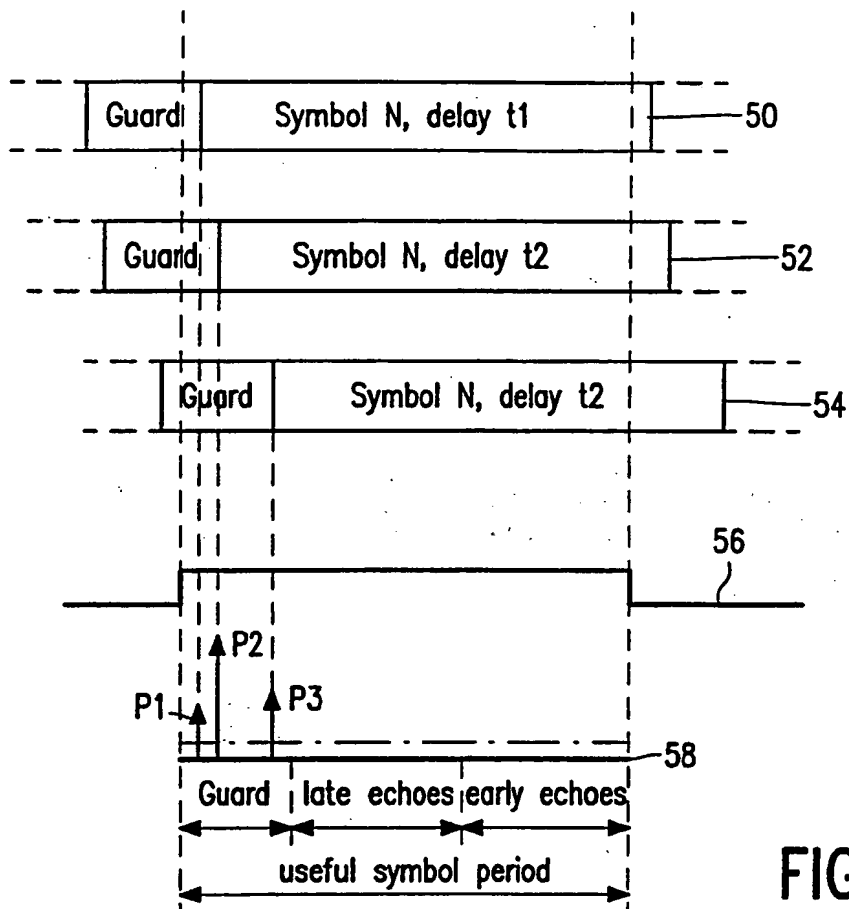


FIG. 3

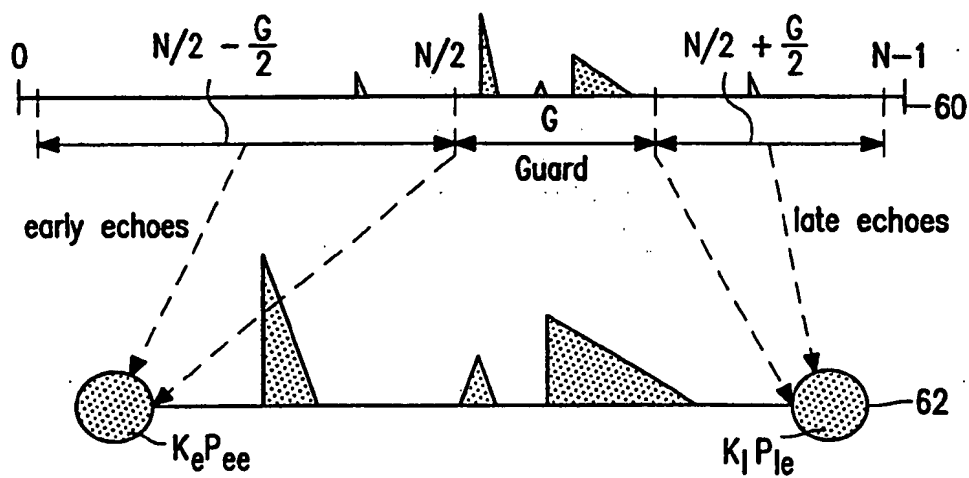


FIG. 4

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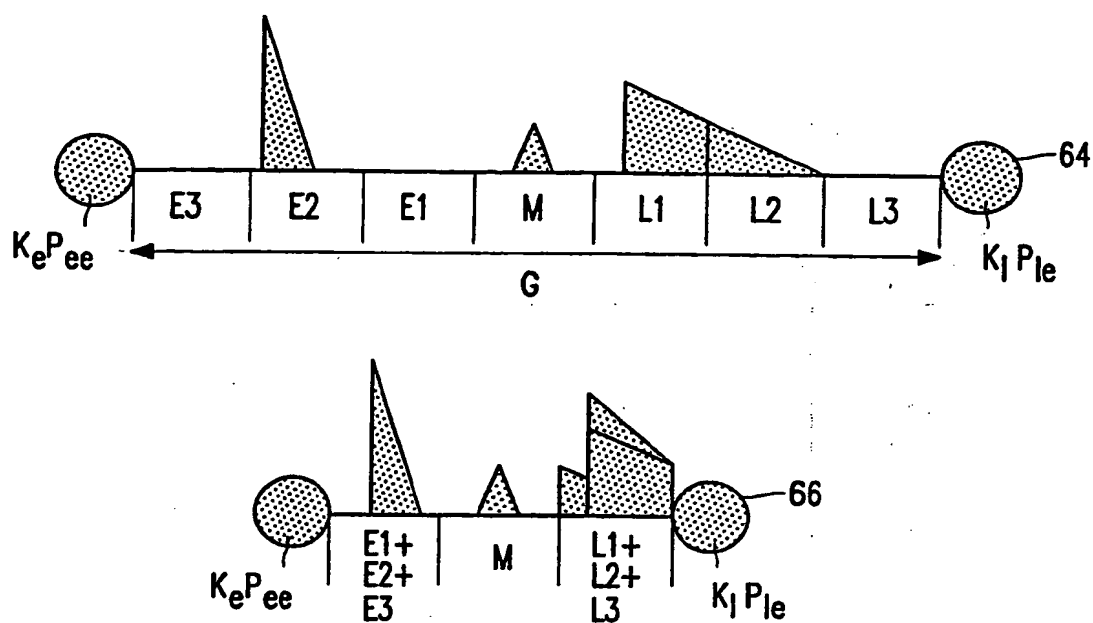


FIG. 5

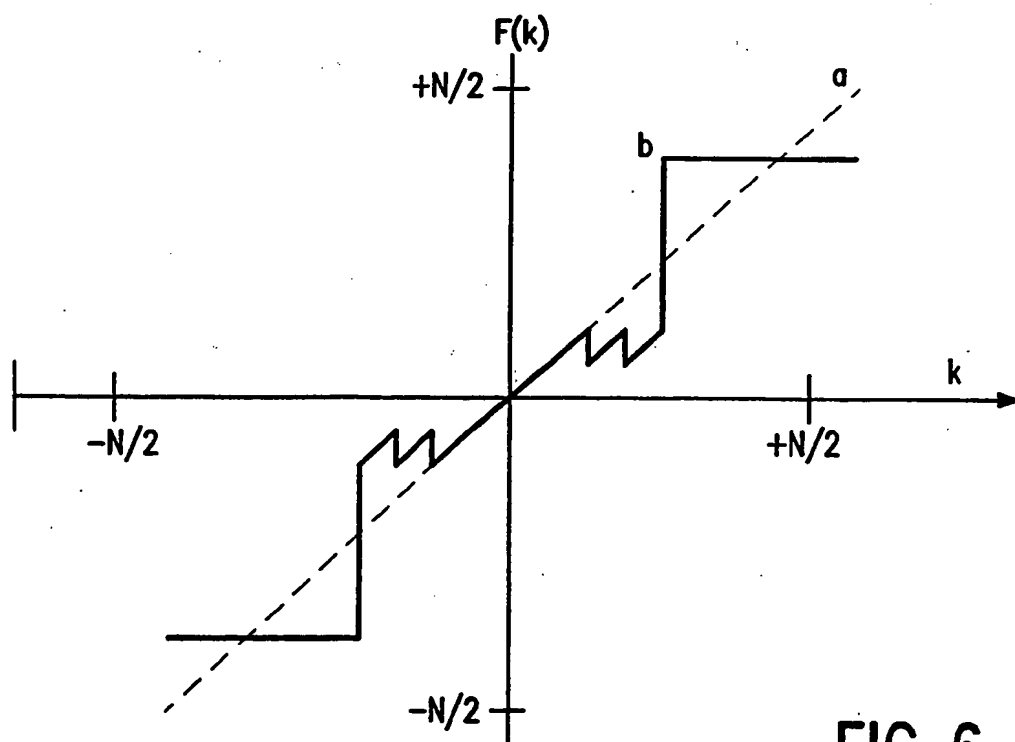


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB 96/00793

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04L 27/26

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IPC6: H04Q, H04L, H04H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	WO 9619056 A1 (HD DIVINE), 20 June 1996 (20.06.96), page 3, line 26 - line 30; page 4, line 12 - line 22; page 7, line 29 - page 8, line 4, page 9, line 9 - line 28 --	1-4,6-9
A,P	US 5521908 A (R.C. YOUNCE ET AL), 28 May 1996 (28.05.96) --	1-10
A	EP 0608024 A1 (LABORATORIES D'ELECTRONIQUE PHILIPS ET AL), 27 July 1994 (27.07.94) -- -----	1,6

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INTERNATIONAL SEARCH REPORT
Information on patent family members

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Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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